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(54) Clamp ring and processing chamber comprising said clamp ring.

(57) Described is a chamber for processing a substrate, e.g. a semiconductor wafer, in which the chamber houses a domed pedestal (18) for supporting the substrate inside the chamber and a clamp ring (32) having a seat (31) formed therein. The seat (31) receives and holds down the periphery of the substrate onto the domed pedestal (18) and includes a substrate engaging surface (34) which engages and holds down the periphery of the substrate. In use the substrate engaging surface (34) defines an angle α to the horizontal which is greater than or equal to the angle β to the horizontal defined by a tangent to the domed pedestal (18) at the point where the periphery of the substrate is held down onto the pedestal (18). Preferably, the angle α to the horizontal defined by the substrate engaging surface (34) is about 3° greater than the angle β of the tangent to the domed pedestal (18) at the point where the substrate is held down onto the pedestal (18). Furthermore described is an improved clamp ring.

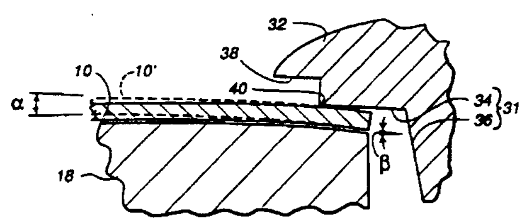

Figure 3

EP 0 595 307 A2

This invention relates to a clamp ring for holding a substrate being processed in a processing chamber as well as to a processing chamber containing that clamp ring.

This invention relates to semiconductor wafer processing reactors and, more particularly, to an improved clamp ring for clamping a semiconductor wafer onto a domed heater pedestal used in such processing reactors.

Semiconductor wafers are generally processed in thermal reactors in which the wafer is subjected to a number of different processing steps. In certain wafer processes, for example physical vapor deposition (PVD), often called sputtering, the wafer to be processed is held down onto a domed heating pedestal by means of some sort of clamping device such as a clamp ring. More details of the PVD/sputtering process itself, and the apparatus used for such processes are disclosed in United States Patent 5,108,569 (Gilboa et al), and are incorporated by reference herein.

An example of a typical PVD wafer processing reactor and how a wafer is mounted therein before processing commences is illustrated with reference to Fig. 1, which is an exploded sectional view of the relevant internal components of the reactor.

Before wafer processing commences, a semiconductor wafer 10 is laterally brought into the reactor by means of a robot arm (not shown). Thereafter, a horseshoe-shaped wafer support 12 moves up from below the wafer 10 until the wafer is supported clear of the robot arm by the flat support faces 14 of four lift fingers 16 (of which only two are shown). In this position the robot arm lies within the open part 17 of the horseshoe-shaped support 12. Thereafter, the robot arm leaves the reactor, and the horseshoe-shaped support 12 continues to move upward. At the same time a wafer heating pedestal 18 moves vertically up into position near the underside of the wafer 10. As is shown in this figure, both the horseshoe-shaped support 12 and the pedestal 18 move vertically up (or down at the end of the processing cycle) along a common, central axis 19, indicated in broken lines.

The pedestal 18 has a domed upper surface and has an outer diameter only slightly smaller than that of the outer diameter of the wafer 10. To enable the pedestal 18 to move up through the center of the support 12 and past the lift fingers 16, four cutouts 20 are formed in the sides of the pedestal. These cutouts are large enough to accommodate the fingers 16 when the pedestal 18 moves up close to the underside of the wafer 10.

The pedestal 18 is typically made of stainless steel and, although not shown, includes a heater element for heating the pedestal 18. This, in turn, heats the wafer 10 during processing operations. To ensure that transfer of heat from the pedestal to the wafer is uniform, gas is injected into the space between the wafer and the pedestal via a gas conduit 22 which is formed in the pedestal 18 and exits in the center of its domed surface. Further details of how this is achieved will be given below.

The horseshoe-shaped support 12 lifts the wafer until it is close to, but not in contact with, a generally circular clamp ring 24. Thereafter, the pedestal 18 pushes up against the underside of the wafer 10, lifting it off the flat faces 14 of the lift fingers 16, and bringing it into contact with a flat faced, annular seat 26 formed in the clamp ring 24.

The pedestal 18 continues to move upward until the clamp ring 24 is lifted clear of its supports (not shown) and is supported only by the wafer 10 resting on the pedestal 18. As the clamp ring 24 is fairly heavy (approximately 3 pounds or 1.35 kilograms), it forces the wafer 10 to adopt approximately the profile of the dome of the pedestal 18. This configuration is illustrated in greater detail in Fig. 2, which is an enlarged detail of the area where the clamp ring 24 engages the edge of the wafer 10. It is in this position that the PVD/sputtering process steps occur.

Fig. 2 illustrates clearly the problem with the prior art clamp rings. As is apparent from this figure, the seat 26 is horizontal, while the pedestal, and accordingly the wafer when it conforms to the shape of the pedestal, are curved. As a result, the point of contact between the heavy clamp ring 24 and the wafer 10 is a sharp right-angled edge 30. The problem with this arrangement is that the wafer's surface can be damaged by the edge 30 gouging into it. Such damage can lead to undesirable particle generation during the processing operations and can result in strain lines from which chipping or flaking of the layers (deposited during subsequent wafer processing) on the surface of the wafer 10 can occur.

This problem is further enhanced when gas is injected into the gas conduit 22. This gas is used to ensure uniform heating of the wafer and is forced into the space between the backside of the wafer 10 and the pedestal 18. The gas, usually an inert gas such as argon, in the space behind the wafer is typically at a pressure of between 5.32 to 15.96 mbar (4 to 12 Torr) while the interior of the reactor is at 5.32 to 13.33 x 10^{-6} bar (4 to 10 milliTorr). As a result of this pressure differential the wafer flexes and bows away from the pedestal 18, with the greatest separation between wafer and pedestal occurring at the center of the wafer, a position indicated by broken lines 10'. Not only does this flexing cause even greater pressure to be exerted on the wafer's surface by edge 30 of the clamp ring 24, but it also causes the edge 30 to scrape the surface of the wafer 10 as the flexing of

the wafer causes its outer edge to move inward toward its center.

In the past, attempts have been made to overcome this problem by very accurately machining and precision polishing the seat 26 and particularly the right-angled edge 30. This machining and polishing process requires a great deal of care by skilled operators and is therefore very costly.

Unfortunately, even the most careful polishing and resulting demurring of the right-angled edge 30 is still not sufficient to provide a totally defect-free edge 30. Any imperfections in this edge 30 act as concentration points for the stress generated by the clamp ring as it holds the wafer down onto the pedestal. These stress concentration points cause damage which can be particularly troublesome as a silicon wafer behaves much like a piece of glass; i.e., a small chip or score mark on the wafer's surface may propagate from the point of stress and shatter the wafer. Additionally, such scoring and marking of the wafer's surface disrupts its planarity. Thus, subsequent processing, for example with a material such as tungsten-CVD, which is difficult to bond to a wafer's surface even under ideal conditions, may not be possible with any measure of reliability as the tungsten may not be able to adhere to the damaged portion of the wafer's surface. As a result, the tungsten may tend to lift away from the entire wafer's surface during further processing thereof.

Other problems with the components of the reactor include an unstable wafer support due to the open-ended horseshoe-shaped support 12 and inexact positioning of the fingers 16. This second problem results from the method of manufacture of the support 12 - it is first machined and thereafter the fingers 16 are welded onto it. Unfortunately this welding is very difficult to achieve accurately and has resulted in misaligned fingers.

The need therefore exists for a better and improved manner of clamping a substrate like a semiconductor wafer onto a domed pedestal in a thermal reactor as well as improving the design of some of the other components within the reactor.

It is therefore the object of the present invention to provide a clamp mechanism which avoids the drawbacks of prior art products. This object is solved by the clamp according to independent claim 1 and the processing chamber comprising the clamp according to independent claim 8. Further advantageous features, details aspects and embodiments of the invention are evident from the dependent claims, the description and the drawings. The claims are to understood as a first non-limiting approach to define the invention in general terms.

This invention relates to semiconductor wafer processing reactors and, more particularly, to an improved clamp ring for clamping a semiconductor wafer onto a domed heater pedestal used in such processing reactors.

Accordingly, the present invention provides an improved thermal reactor for processing a substrate like a semiconductor wafer. The reactor includes a domed pedestal for supporting the substrate and controlling its temperature, and a clamp ring which includes an annular seat formed therein, for receiving and holding down the periphery of the substrate onto the domed pedestal. The seat formed in the clamp ring includes a substrate engaging surface which engages and holds down the periphery of the substrate and which is formed to define, in use, an angle to the horizontal which is greater than or equal to the elevational angle of a tangent to the domed pedestal at the point where the periphery of the substrate is held down onto the pedestal.

Preferably, the seat defines an angle of 4° to the horizontal. This angle is typically 3° greater than the elevational angle of the tangent to the domed pedestal at the point where the substrate is held down onto the pedestal.

In addition, the inner edge of the seat can be formed with a rounded corner, thereby reducing the chances of scoring the wafer's surface.

This invention has the advantage that the seat which holds the periphery of the substrate down onto the domed pedestal presents a much larger surface area to the upper surface of the substrate than in prior art devices.

Another advantage of this invention is that no sharp edges on the clamp ring bear onto the substrate surface. Accordingly, damage of the substrate surface is minimized.

These and other advantages of the present invention will with no doubt become apparent to those skilled in the art after having read the following detailed description of the preferred embodiment which is illustrated in the several figures of the drawing.

In the accompanying drawings:

Fig. 1 is a partially sectioned, exploded view of the internal components of a semiconductor processing thermal reactor according to the prior art;

Fig. 2 is a detail of the clamp ring in Fig. 1 showing how the ring engages the wafer's surface;

Fig. 3 is a section, similar to that of Fig. 2, illustrating one embodiment of the invention;

Fig. 4 is a figure similar to that in Fig. 3, illustrating a different embodiment of the invention;

Fig. 5 is a plan view of a wafer support ring and a domed pedestal; and

Fig. 6 is a section along line 6-6 in Fig. 5.

The basic principle of this invention is illustrated in Fig. 3. This figure is a cross-section illustrating how a substrate, in this case a semiconductor wafer 10 is held down onto a domed pedestal 18 by a stainless steel clamp ring 32 of the invention.

As is illustrated, the clamp ring 32 has an annular seat 31 formed therein. The seat 31 includes a wafer-engaging surface 34 and a sloped sidewall 36. The wafer engaging surface 34 is approximately 1.8 mm (0.071") wide and holds the periphery of the wafer 10 down onto a domed heater pedestal 18 similar to that illustrated in Fig. 1. The clamp ring 32 also includes a roof portion 38 which is formed concentrically with the waferengaging surface 34, but is located inwardly thereof.

As with the apparatus illustrated in Figs. 1 and 2, the wafer assumes a domed profile roughly corresponding to that of the dome of the pedestal 18 when it is clamped onto the pedestal. However, in terms of this invention, the waferengaging surface 34 is formed so that, when it is in use, it defines an angle α to the horizontal. This angle α is greater than the angle β between the tangent to the domed surface, at the point where the wafer is held down onto the pedestal 18, and the horizontal, that is, a plane perpendicular the central axis 19 along which the elements are moved. As illustrated in this figure, the curvature of the dome is greatly exaggerated to aid in illustration. Preferably, the angle α is at least 1° larger than the angle β. In actuality, the angle β is approximately 1°. Typically, the angle α will be approximately 4°.

As a result of this arrangement, when gas is injected into the space between the backside of the wafer 10 and the pedestal 18 (as described with reference to the prior art) and the wafer bulges to the position 10' indicated in broken lines, a substantial amount of contact area is presented, by the waferengaging surface 34, to the upper surface of the wafer 10. In addition, as angle α is much greater than angle β, this allows for a substantial flexing of the wafer 10 before the inner edge 40 of the wafer-engaging surface 34 comes into contact with the surface of the wafer.

As the periphery of the wafer 10 is supported by a flat surface, as opposed to the sharp edge of the prior art devices, the marking of its upper surface is substantially reduced. Furthermore, it has been found that the clamp ring of this invention holds the periphery of the wafer down onto the pedestal 18 so that a better seal is formed between the pedestal and the periphery of the wafer, which reduces the amount of pressurized gas from escaping from underneath the wafer. Accordingly, the pressure of the gas can be increased by between 6% to 10% which allows for greater uniformity of heating across the surface of the wafer.

From this figure, it will also be noted that the sidewall 36 of the clamp ring is angled back from the vertical. Typically, this angle is in the region of 10°. This angled sidewall 36, in addition to defining the outer edge of the wafer-engaging surface 34, also serves to guide the wafer and pedestal as these move up toward the clamp ring 32.

An alternative embodiment to that illustrated in Fig. 3 is illustrated in Fig. 4. In this figure, the clamp ring 42 has its wafer-engaging surface 44 angled at approximately 1° to the horizontal. This angle is still equal to or greater than the angle β - (between the tangent and the horizontal) and therefore still allows the wafer 10 to flex to the position 10'. The clamp ring 42 includes a sidewall 46 and a roof portion 48 similar to corresponding elements in Fig. 3. Wafer engaging surface 44 and sidewall 46 form a seat 41 similar to the corresponding elements shown in Fig. 3.

In addition, the interior edge 50 of the wafer-engaging surface 44 is rounded with a radius of curvature of approximately 0.58 mm (0.023") or greater. As a result of this configuration, there is no way in which the flexing wafer can be engaged by a sharp 90° edge but is, instead, presented with a rounded surface. This in turn reduces the possibility of damage to the wafer's upper surface.

In Figs. 5 and 6, referred to here jointly, details of an improved wafer support 52 and its associated lift fingers 56 are illustrated. From Fig. 5, it can be seen that the support 52 takes the form of a continuous ring as opposed to the horseshoe-shape of prior art support. In addition, the position of a heater pedestal 58 is also shown (in broken lines) in Fig. 5. From this figure, the cutouts 60 in the pedestal 58 and the manner in which the wafer lift fingers 56 fit into these cutouts are clearly evident.

From both Figs. 5 and 6 it can be seen that the wafer support ring 52 can be attached to a standard lifting mechanism (not shown) at an attaching tab 62 on one side of the ring 52. This is typically done by riveting the tab 62 down onto the lifting mechanism.

At the opposite side of the ring 52 to the tab 62, a stepped-down brace 64 is formed between the arms of the ring 52. This stepped brace 64 effectively lowers the top of the ring 52 at this section and provides an entrance passageway for a robot arm which inserts and removes the wafer from the thermal reactor. If it were not for this stepped brace 64, the horseshoe-shaped support of the prior art would be required. It will be apparent that the closed ring is advantageous as it provides a more sturdy support for the fingers than the open ended horseshoe shape.

The lift fingers, as can be seen from Fig. 6 in particular, have flat wafer support faces 54 which

engage the wafer to lift it off the robot arm. To ensure that this can be done and that the wafer is positioned accurately on the lift fingers, each lift finger 56 has a sloping side 66 which serves to guide the wafer down into position onto the support faces 54. To ensure that the fingers themselves are positioned correctly onto the ring, the fingers are welded onto the ring during the initial manufacturing steps. Thereafter the ring is machined together with the fingers, thereby ensuring that the fingers are accurately positioned with respect to both the support ring and the clamp ring with which they will interact with during wafer loading and unloading.

Although the present invention has been described above in terms of a specific embodiment, it is anticipated that alterations and modifications thereof will no doubt become apparent to those skilled in the art. For example this invention could be applied in wafer etching apparatus where, instead of a continuous wafer engaging surface 34, an intermittent engaging surface is provided. Furthermore, the pedestal can be used for cooling as well as heating. Also, the precise shape of the dome is not critical to this invention and the wafer need not be a semiconductor wafer but could be a substrate of another material type. It is therefore intended that the following claims be interpreted as covering all such alterations and modifications as fall within the true spirit and scope off the invention.

Claims

1. A clamp ring (32) for holding a substrate (10) being processed against a domed pedestal (18) said clamp ring (32) comprising:
   an outer peripheral section having a shape conforming to an outer periphery of the domed pedestal (18) and completely enclosing an inner aperture to expose a major portion of the substrate (10) and
   an inner seat (31) including a substrate engaging surface (34) for holding an outer peripheral edge of the substrate (10) against the domed pedestal (18), said substrate engaging surface (34) being inclined at a first angle away from a plane perpendicular from a direction in which said substrate (10) is being held against said domed pedestal (18) and being inclined toward a domed peak of said domed pedestal (18).

2. The clamp ring (32) as recited in claim 1, wherein said domed pedestal (18) has a substantially circularly shaped upper domed surface and said outer peripheral sections and said inner seat (31) are substantially annularly shaped.

3. The claim ring (32) as recited in claim 1 or 2, wherein a domed surface of said domed pedestal (18) at the point at which said substrate (10) is held against said domed surface is inclined away from said perpendicular plane by a second angle less than said first angle.

4. A clamping assembly for holding a substrate (10) during processing, comprising:
   a domed pedestal (18) having a domed surface, generally circularly symmetric about a first axis, and
   a clamping ring (32) movable along said first axis relative to said domed pedestal (18) and including an annular engaging surface (34) for holding the substrate (10) against the domed surface at a contacting portion thereof,
   wherein said contacting portion is inclined at a first angle β from a perpendicular plane to said first axis,
   said engaging surface (34) is inclined at a second angle α from said perpendicular plane, and
   wherein said angle α is greater than or equal to said first angle β.

5. The clamping assembly as recited in claim 4, wherein said second angle α is greater than said first angle β by a differential angle.

6. The clamping assembly as recited in claim 5, wherein said differential angle is in a range between one-half and four degrees.

7. The clamping assembly as recited in claim 6, wherein said differential angle is in a range between one and three degrees.

8. An apparatus for processing a substrate (10), the apparatus including a chamber, a pedestal (18) having a domed surface for supporting the substrate (10) inside the chamber, and a circumscribing clamp ring (32,42) for engaging and holding down the periphery of the substrate (10) onto the domed pedestal (18) whereby the clamp ring (32, 42) comprises:
   a body,
   a seat (31, 41) formed in the body, the seat (31, 41) including a substrate engaging surface (34, 44) for engaging and holding down the periphery of the substrate (10) and which, in use, defines an angle α to the horizontal which is greater than or equal to the angle β to the horizontal defined by a tangent to the domed surface of the pedestal (18) at the point where the periphery of the substrate (10) is held down onto the pedestal (18).

9. The processing chamber as recited in claim 8, wherein the angle α to the horizontal defined by the seat (31) is about 3° greater than the angle β of the tangent to the pedestal (18) at the point where the substrate (10) is held down onto the pedestal (18).

10. The processing chamber as recited in claim 8 or 9, wherein the seat (31, 41) defines an angle of about 4° to the horizontal.

11. The processing chamber as recited in one of claims 8 to 10, wherein the seat (41), includes an inner edge (50) and wherein the inner edge (50) is formed with a rounded corner.

12. The processing chamber as recited in one of claims 8 to 11, wherein the pedestal (18) and the clamp ring (32, 42) have a common axis, and wherein the pedestal (18) is movable along the common axis to urge the substrate (10) into engagement with the clamp ring (32, 42) such that the substrate (10) bows in conformance with the profile of the pedestal (18).

13. The processing chamber according to one of claims 8 to 12, further comprising a fluid transport conduit formed in the pedestal (18) to exit at the interface between the pedestal (18) and the substrate (10), the fluid conduit being for injecting fluid at the interface between the pedestal (18) and the substrate (10), whereby the fluid lifts at least part of the substrate (10) from the surface of the domed pedestal (18), and further urges the substrate into engagement with the substrate engaging surface (34, 44).

14. The processing chamber according to claim 13, wherein the pedestal (18) includes a heater element which, in use, heats the pedestal (18), which heats the fluid and which, in turn, heats the substrate (10).

15. Support ring (52) comprising an attaching tab (62) and arms extending from said attaching tab (62), characterized in that a stepped-down brace (64) is formed between the arms of the support ring (52) at the opposite side of the attaching tab (62).

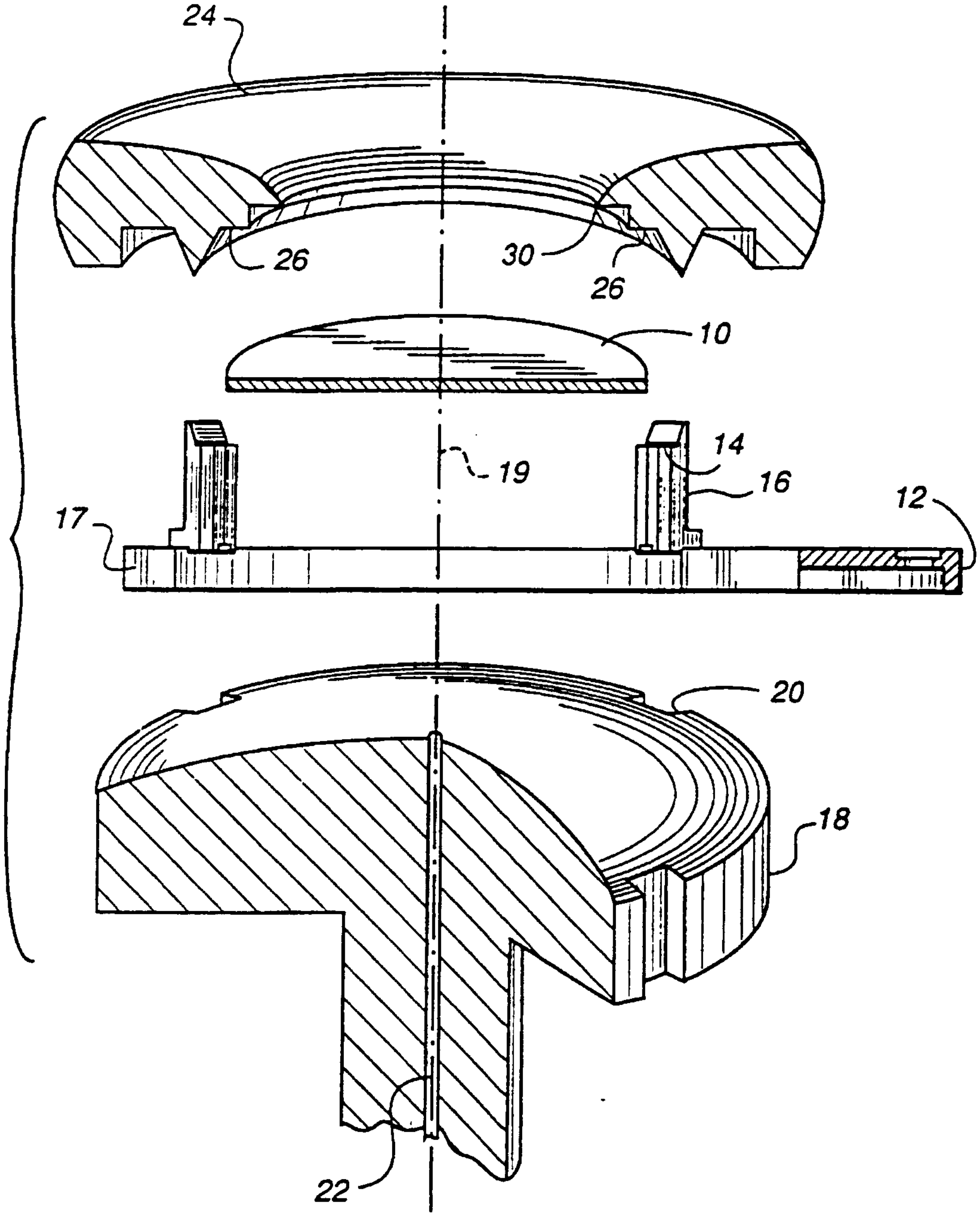

Figure 1 (PRIOR ART)

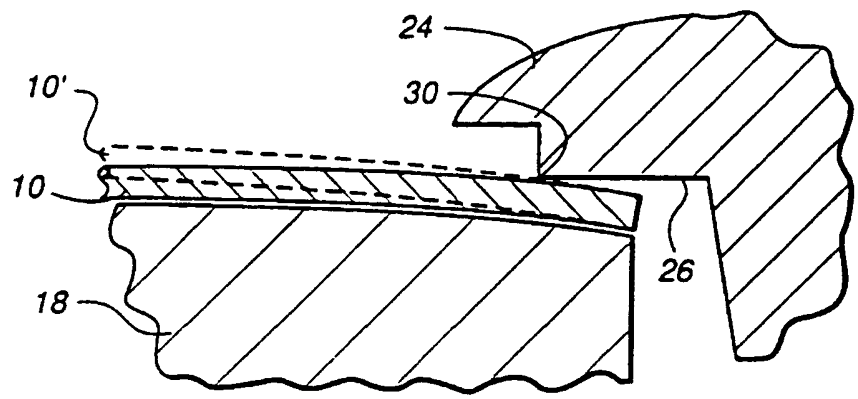

Figure 2 (PRIOR ART)

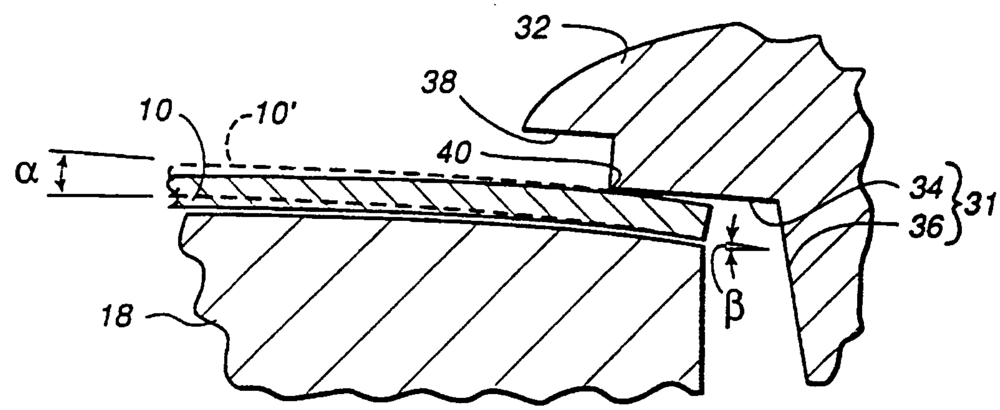

Figure 3

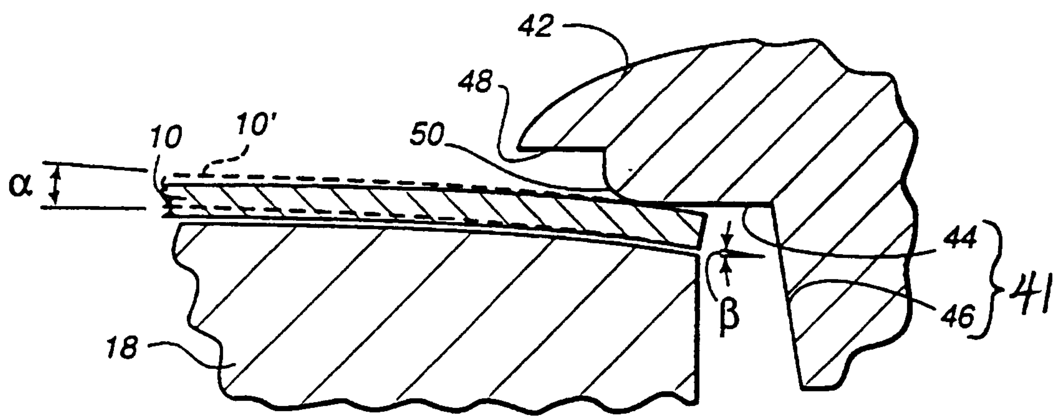

Figure 4

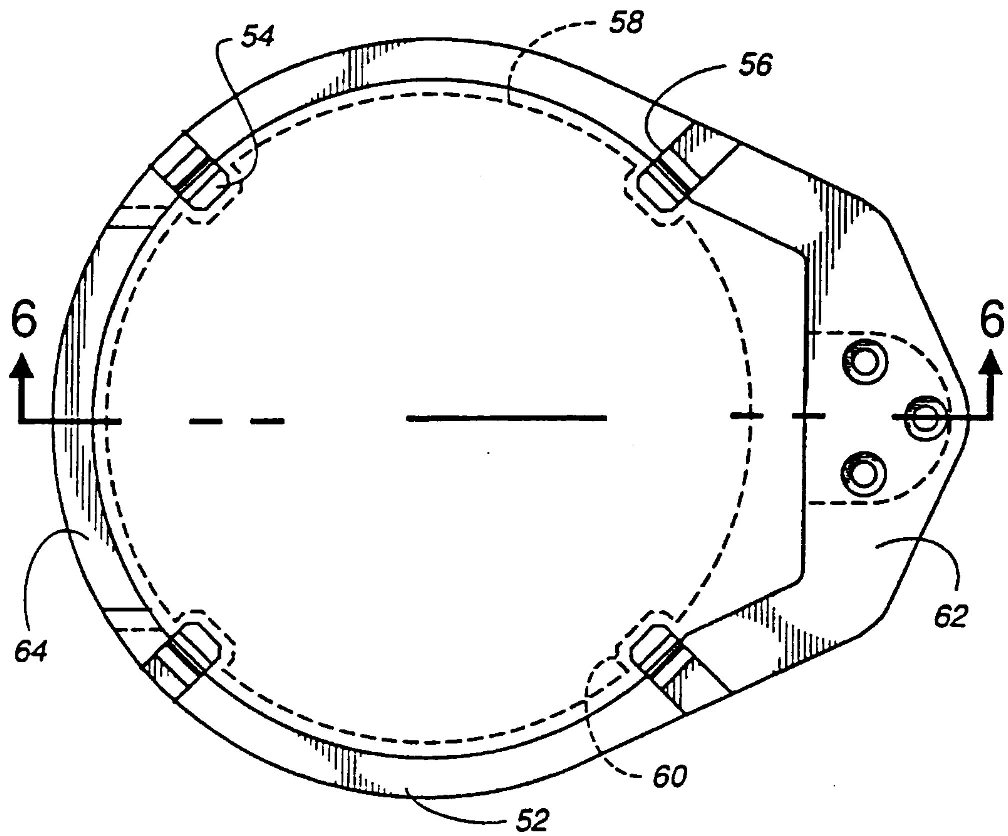

Figure 5

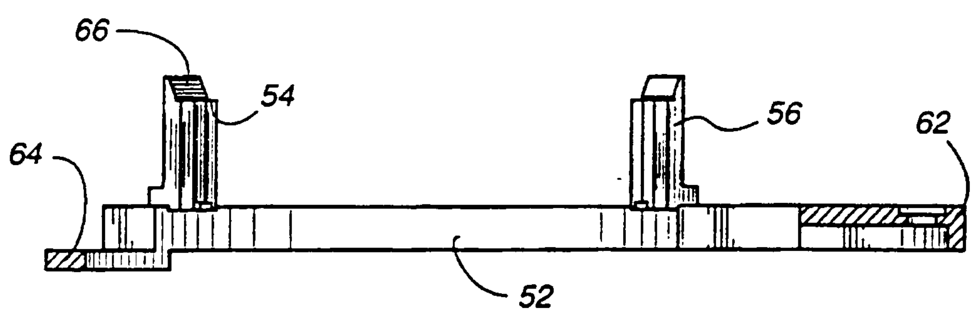

Figure 6

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(12) **EUROPEAN PATENT APPLICATION**

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(54) **Clamp ring and processing chamber comprising said clamp ring.**

(57) Described is a chamber for processing a substrate, e.g. a semiconductor wafer, in which the chamber houses a domed pedestal (18) for supporting the substrate inside the chamber and a clamp ring (32) having a seat (31) formed therein. The seat (31) receives and holds down the periphery of the substrate onto the domed pedestal (18) and includes a substrate engaging surface (34) which engages and holds down the periphery of the substrate. In use the substrate engaging surface (34) defines an angle α to the horizontal which is greater than or equal to the angle β to the horizontal defined by a tangent to the domed pedestal (18) at the point where the periphery of the substrate is held down onto the pedestal (18). Preferably, the angle α to the horizontal defined by the substrate engaging surface (34) is about 3° greater than the angle β of the tangent to the domed pedestal (18) at the point where the substrate is held down onto the pedestal (18). Furthermore described is an improved clamp ring.

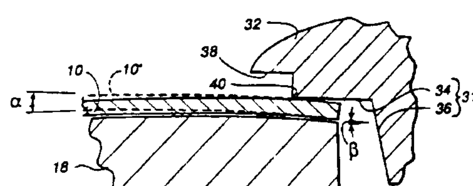

Figure 3

EP 0 595 307 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 93 11 7441

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
X	EP-A-0 339 580 (APPLIED MATERIALS) * column 16, line 36 - column 17, line 29; claims 1,16; figures 7,13A,13B * ---	1,2,4,8, 12,13	H01L21/00
A	EP-A-0 095 372 (VARIAN) * page 10, line 24 - page 12, line 29; claim 1; figures 1A-2C * ---	1,2,4,8, 13	
A	EP-A-0 452 779 (APPLIED MATERIALS) * figure 3 * ---	15	
D,A	EP-A-0 430 229 (APPLIED MATERIALS) * column 6, line 4 - line 18; figure 2 * -----	1,8,13, 14	
			TECHNICAL FIELDS SEARCHED (Int.Cl.5)
			H01L C23C H01J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	23 March 1994	Rieutort, A

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

European Patent Office

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing more than ten claims.

☐ All claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for all claims.

☐ Only part of the claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims and for those claims for which claims fees have been paid.

namely claims:

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirement of unity of invention and relates to several inventions or groups of inventions,

namely:

see sheet -B-

☒ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid.

namely claims:

☐ None of the further search fees has been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims.

namely claims

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirement of unity of invention and relates to several inventions or groups of inventions,
namely:

1. Claims 1-14 : Clamp ring for wafer on domed pedestal.

2. Claim 15 : Support ring for loading wafer on pedestal.